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Investigation into the Dynamic Properties of Jute Fibre Reinforced Concrete

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Authors' contributions

This work was carried out in collaboration between all authors. Author GMA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AON and SOAO managed the analyses of the study. Author GMA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Concrete as construction material has been marked with little resistance to crack, low tensile strength and limited ductility. Corrosion in reinforcing steel is also a major problem faced in reinforced concrete construction, which significantly affect the life and strength of concrete structures. Thus, the research aimed at investigating the dynamic properties of jute fibre reinforced concrete. Randomly dispersed jute fibres were added to concrete of grade 20 MPa in varying percentage range of 0 to 2% in step of 0.5 by weight of concrete. Concrete specimens of cube size (120 × 120 × 120) mm^3 were cast from the mix and cured for 28 days. The impact resistance of Jute Fibre Reinforced Concrete (JFRC) was investigated using falling dart machine. The results depicted that 2% JFRC at 14 days age of curing had the highest average number of blows, impact energy and impact strength of 115, 4098.60 kNmm and 284.63 N/mm^2, respectively compared to control (0% jute fibre) at 14 days curing age of 27, 962.28 kNmm and 66.83 N/mm^2, respectively. The impact strength of JFRC increases with increase percentage dosage of jute fibre. The increase

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in jute fibre content in the concrete further increase the number of blows as well as impact energy required for the final failure of the concrete. The inclusion of jute fibre to concrete abetted as crack arrestor, and substantially improved the concrete dynamic properties.

Keywords: Jute fibre concrete; impact energy; impact strength.

1. INTRODUCTION

Concrete is most widely used man-made construction material in the world. The strength, durability and other characteristics of concrete depend upon the properties of its ingredients, on the proportions of mix, the method of compaction and other controls during placing, compaction and curing. In most cases, conventional steel reinforcements or prestressing tendons are used to enhance the strength and durability of concrete during construction. The advantage of reinforcing and pre-stressing technology utilization with steel reinforcement and steel wires have helped in overcoming the incapacity of concrete in tension but the low ductility magnitude and compressive strength are yet to be overcome.

Recently, attempts had been made by various researchers to incorporate relatively large volumes of fibres such as steel, glass and synthetic fibres in concrete. Li et al. [1] opined that the behaviour of fibre-reinforced concrete changed with varying concrete mixes, fibre materials, geometries, distribution, orientation, and densities. In addition, Higashiyama and Banthia [2] observed that concrete properties such as tensile, flexure, fracture, toughness, fatigue, impact, wear and thermal shock; had substantially been improved by fibre addition to concrete. The inclusion of fibre was further noticed by the authors, to prevent crack propagation in concrete.

Chandramouli et al. [3] investigated tensile properties of glass, polypropylene and steel fibres in concrete. Results of tensile tests carried out by the researchers indicated that large volume of aligned fibres in concrete substantially enhanced tensile carrying capacity of concrete. Sangeetha [4] studied the effect of addition of combination of admixtures on the strength properties like compressive strength, split tensile strength, flexural strength and impact strength of polypropylene fibre reinforced concrete. Bindiganivile and Banthia [5] investigated the fibre matrix bond behaviour under impact loading on concrete. The authors submitted that fibre matrix bond strength played important roles in impact strength of FRC. Also that high strength fibre matrix results in stiffer bond.

Mindess and Zhary [6] studied impact resistance of Fibre Reinforced Concrete (FRC). The authors concluded that FRC specimen showed deformation greater than the control specimen, when subjected to compressive impact loading and higher deformation were exhibited by FRC by increasing the drop height. Ravikumar and Thandavamoorthy [7] also incorporated polyesters fibre in concrete pavements with view of controlling the micro shrinkage cracks induced during hydration. The authors discovered the fibre improved the flexural strength and energy absorption of concrete. Olutoge et al. [8] improved the strength of concrete with addition of steel fibres. The researchers observed the presence of steel fibre in concrete to minimize crack propagation, improves concrete bonding and ductility over conventional concrete.

Zhou et al. [9] considered jute fibres as agriculture waste and engineering natural materials and with consequent economic option for construction industries. Aziz and Mansur [10] observed jute fibre reinforced concrete to behave as homogeneous material within certain limits. The random distribution and high surface to volume ratio of the fibres results in a better crack-arresting mechanism. Adhikari et al. [11] predicted potential application of jute fibre reinforced cement concrete as structural items in construction industry. The authors advocated the use of jute as reinforcing fibre in cement concrete; that being a potential agricultural product, it will promote jute farming industries as well as produce better advanced composites. However, there is dearth of information on resistant of jute fibre reinforced concrete under impact loading. Therefore, the paper aimed at examining the dynamic properties of jute fibre reinforced concrete.

2. SIGNIFICANCE OF STUDY

As concrete increasingly becomes an important building material in construction industries, studies into the potential use of fibre in modified concrete therefore becomes imperative; which lead to the use of jute fibre as an additive in concrete which increases the bond and act as cracks arrestor to improve the static and dynamic properties of concrete.

3. MATERIALS AND METHODS

3.1 Materials

The materials used in this study include ordinary Portland cement, fine aggregate, coarse aggregate, mixing water and jute fibre. Preliminary tests were carried out on the materials, the test aimed at examining the physical and mechanical properties of the materials used. Detail of the test performed on materials include fineness test, consistency test, soundness test, settling time, bulk density, specific gravity and particle size distribution test. The properties of some of these materials were described below.

3.1.1 Cement

The cement used in all mixtures of this research was ordinary Portland cement of 43 grade; which conforming to BS 12, [12] was used as it is readily available in local market in Nigeria. The conforming weight of each bag of cement is 50 kg. The results for the physical and mechanical properties of cement were as presented in Table 1 and its chemical composition was presented in Table 2.

Table 1. Physical and mechanical properties of cement used as per manufacturer's specifications

Test	Results
Density	3.09 g/cm^3
Fineness	92%
Normal consistency	30%
Soundness	0.8 mm
Setting time	
Initial	2 hrs 10 mins
Final	3 hrs 10 mins
Compressive strength	
7 days	33 MPa
28 days	43 MPa

Cement show early strength development pattern, of about 77% of 28 days strength in 7 days. Cement users can remove formwork in early days. Initial setting time of the cement sample was 130 minutes while final setting time was 190 minutes. This implies that the cement has quite stable setting times. According to both SLS 107 [13] requirements and EN 197 [14], initial setting time should be higher than 60 minutes while final setting time should be less than 600 minutes according to BS12 [12] requirements. Cement sample was within limits stated by EN and SLS standards [13,14]. The cement was said to be fine since 92% of sample passed through 0.425 µm sieve size. Cement sample show much soundness, compared to both SLS 107 [13] and EN 197 [14] standards requirements of not more than 10 mm. According to EN 197 [14] limit for maximum sulphate (SO_3) content of 3.5% According to SLS 107 [13], limit maximum sulphate SO_3 content to 3% if C_3A content is more than 5% and maximum sulphate SO_3 content should not exceed 2.5% if C_3A content is less more than 5% Cement sample was found to be within limits stated by EN and SLS standards [13,14]. According to SLS 107, limit maximum Magnesium oxide MgO content to 5% [13]. Cement samples are within limits stated by SLS standards [13].

3.1.2 Aggregates

The main aggregates type used in this research work were crushed rock coarse aggregate. The fine aggregate was well graded sharp sand from a locally available river that passes through 4.75 mm sieve and retained on 2.36 mm sieve and the coarse aggregate was granite with the maximum aggregate size limited to 12.5 mm obtained from a quarry in Abeokuta. The fine aggregate was air- dried, Specific gravity and sieve analysis test were carried out for fine and coarse aggregate at Moshood Abiola Polytechnic Civil Engineering Laboratory. They were carried out in accordance with BS 882 [15]. The particle size distribution of the aggregates meets the ASTM C33 grading requirement for fine and coarse aggregates respectively [16]. The sieve analysis graph divulges the aggregates to be well graded; with fineness modulus of fine and coarse aggregates of 2.76 and 3.49, respectively.

3.1.3 Mixing water

Pipe borne water from Moshood Abiola Polytechnic Campus was used as mixing water. It was drinkable, clear, free from oil, apparently clean and contained no substance at excessive amount that could be harmful to the concrete.

Table 2. Chemical analysis of the cement used as per manufacturer's specifications

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3^{2-}	LOI
Content (%)	65.81	20.60	4.98	3.89	1.89	0.56	0.35	1.35	2.70

3.1.4 Jute fibre

The jute fibre used in this research work was obtained from local market. The specifications of jute fibre as per manufacturer were presented in Table 3. The jute fibres were chopped to about 30 mm or less in order to be well mixed to the concrete without dogging or honeycombing. Fig. 1 showed the sample of the fibre.

3.2 Methods

3.2.1 Mix proportioning

Five mixes were prepared in five batches in which jute fibre was used as admixture in four batches and one batch for control specimen; which were added up to make five batches. The concrete was designed to have good properties notably in the area of strength and impermeability. Water cement ratio was kept constant throughout the mixes. Batching was done by weighing the material for the concrete specimens using a weighing balance. The mix proportions by weight and the mix designations were presented in Table 4.

3.2.2 Preparation and casting of concrete specimens

The concrete mixture was prepared manually on a smooth concrete slab. The ground was first clean and dampened with water. The jute fibre was mixed with the weighed coarse aggregate; before required fine aggregate was placed and mixed for about 2 minutes with one-third of the mixing water added. Then cement and the remaining two-third of the mixing water were added and mixed for about another 2 minutes. The mixing of plain concrete was similar to jute fibre reinforced concrete, except that; jute fibre addition was eliminated in the matrix. The concrete was mixed, and placed inside the mould which was already smeared with oil so as to enhance easy removal of the set concrete. The concrete mixed for each batch were compacted by the use of tamping rod and the moulds were externally vibrated to remove trapped air which could reduce the strength of the concrete. Then the specimens were left to cure for 24 ± ½ hours in the mould in the laboratory environment. De-moulding took place on the second day after casting when the final setting had been reached. The specimens were stored at room temperature in a curing tank of water until the curing age of specimen was reached.

Fig. 1. Chopped jute fibre sample

Table 3. Specification of jute fibre used

Fibre type	Length L (m)	Diameter D (μm)	Aspect ratio l / d	Specific gravity	Density of jute fibre	Tensile strength (MPa)
Cotton	1 - 4	17 - 20	110	1.3	1460	393 -773

Source: Zhou et al. [9]

Table 4. Mixture proportions

Mix designation	Mix type	Volumetric fibre dosage v_f (%)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)
M_1	Control	0	1.813	3.626	7.252	1.088
M_2	JFRC	0.5	1.813	3.626	7.252	1.088
M_3	JFRC	1.0	1.813	3.626	7.252	1.088
M_4	JFRC	1.5	1.813	3.626	7.252	1.088
M_5	JFRC	2.0	1.813	3.626	7.252	1.088

3.3 Experiment Procedure

Tests were carried out on fresh concrete and hardened concrete (JFRC and Plain concrete) in order to determine their physical and mechanical properties. The details of the test carried out on strength characteristic of the concrete and the procedures were discussed.

3.3.1 Impact strength test

The specimens for impact test were cast in cube mould of dimensional size of 120 mm × 120 mm × 120 mm. 9 cubes specimen were made from every batch, thus the total number of cube specimen under impact were 45. The cubes specimens were left to cure for 24 hours in the laboratory environment as earlier discussed. The next day the cubes were demoulded, weighed and then placed in the curing tank filled with water till curing ages. After the curing ages, cubes specimens were tested under impact load of the drop-weight testing machine. Prior to the testing, the specimen were drain off excess water from the surface, weighed and then placed in the machine; load was applied on the cube by releasing the hammer of the machine on the cube specimen. The number of blows to cause the first crack (initial crack) N_1 and the number of blow to cause final failure N_2 were also noted. Three cube specimens were tested and their average value and also the number of blow on each cube were used to determine the impact energy required by each cube before failure.

Fig. 2. Impact strength test

3.3.2 Mathematical approach for calculating impact energy

The impact energy *U was* calculated for each concrete specimen using equation (1).

$$\mathrm{U} = \frac{n.mv^2}{2} \quad (1)$$

$$\mathrm{H} = \frac{gt^2}{2} \quad (2)$$

$$\mathrm{v} = g.t \quad (3)$$

$$\mathrm{m} = \frac{W}{g} \quad (4)$$

Where,

H = falling height of hammer,
v = velocity of the hammer at impact,
w = hammer weight,
m = drop mass (mass of the hammer),
g = acceleration due to gravity,
t = time required for the hammer to fall from a height of 247 mm,
n = number of blows and

Also, the impact strength was calculated using equation below:

$$\mathrm{a}_{cu} = \frac{U}{hb} \times 10^3 \quad (5)$$

Where

a_{cu} = impact strength
U = impact energy
b = width of the sample
h = *thickness* of the sample

The number of blows and impact energy required to cause the first visible crack (N_1) and final failure (N_2) of JFRC specimens were indexed in Table 5.

$$247 = \frac{9810 \times \mathrm{t}^2}{2}$$

t = 0.23 *s; v* = 9810 × 0.23 = 2256.3 mm/s; W= 14 × 9.81 = *137*.34 and n = 0.1373 kN

The impact energy delivered by hammer per blow for each cube was obtained by substituting the values in equation (1), given as:

$$U = \;no\;of\;blow \times \frac{0.1373 \times 2256.3^2}{2 \times 9810}$$

U = (no of blosw× 35.64) kNmm.

The impact energy of each specimen was calculated by substituting the corresponding values of *t, v,* w and *n* oobtained from the experimental test into equations (2) - (4) above.

4. RESULTS AND DISCUSSION

4.1 Results of Impact Energy and Number of Blow for JFRC

The number of blows and impact strength required to cause the first visible crack (N_1) and final failure (N_2) of JFRC specimens were indexed in Table 5, Figs. 3 and 4, respectively.

From Table 5 and Fig. 3, the results revealed direct proportionate increase in the percentage of jute fibre with number of blows which proportionally increase the impact energy of the concrete. The 2% JFRC at 14 days age of curing had the highest average number of blows, impact energy and impact strength of 115, 4098.60 kNmm and 284.63 N/mm^2, respectively compared to control 0% jute fibre) at 14 days curing age of 27, 962.28 kNmm and 66.83 N/mm^2, respectively. From the results increase in jute fibre content in the concrete were proportioned to increase in the number of blows required for the final cracks or failure of the specimen. This depicted that addition of jute fibres in concrete improved bonding characteristic within the concrete.

The results in Fig. 4 showed all specimens had substantial impact strength values within the early age of curing; whereas there was reduction in impact strength of concrete specimens at 28 days curing age. Furthermore, significant increases in impact strength of JFRC specimens compared to the control were noticed. This significantly affected the impact energy required to cause failure of each specimen under impact load as shown in Table 5. Therefore, caused the failure of jute fibre concrete was minimal compared to control concrete.

Table 5. Summarize representation of impact energy and number of blow for JFRC

Curing (days)	Mixes	Jute fibre content (%)	N_1 / N_2		
			Average no of blows	Average impact energy (kNmm)	Impact strength N/mm^2
7	M1	0	4.0 / 21.0	142.56 / 748.44	9.90 / 51.98
	M2	0.5	8.0 / 34.7	285.12 / 1236.71	19.80 / 85.88
	M3	1.0	6.0 / 35.0	213.84 / 1247.40	14.85 / 86.63
	M4	1.5	7.6 / 36.0	270.86 / 1283.04	18.81 / 89.10
	M5	2.0	11 / 48.5	392.04 / 1728.54	27.23 / 120.04
14	M1	0.0	4.5 / 27.0	160.38 / 962.28	11.14 / 66.83
	M2	0.5	9.0 / 56.3	320.76 / 2006.53	22.28 / 139.34
	M3	1.0	6.0 / 79.3	213.84 / 2826.25	14.85 / 196.27
	M4	1.5	7.6 / 92.7	270.86 / 3303.83	18.81 / 229.43
	M5	2.0	11 / 115	392.04 / 4098.60	27.23 / 284.63
28	M1	0.0	4.33 / 14.0	154.32 / 487.08	10.72 / 33.83
	M2	0.5	6.67 / 45.0	237.72 / 1605.13	16.51 / 111.47
	M3	1.0	3.3 / 39.0	117.61 / 1389.96	8.17 / 96.53
	M4	1.5	3.67 / 57.3	130.80 / 2043.36	9.08 / 141.90
	M5	2.0	4.0 / 62.7	142.56 / 2233.44	9.90 / 155.10

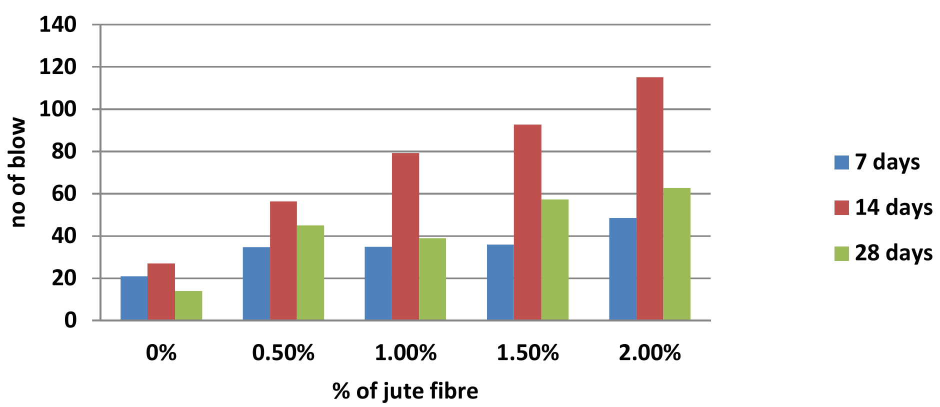

Fig. 3. JFRC number of blow at failure

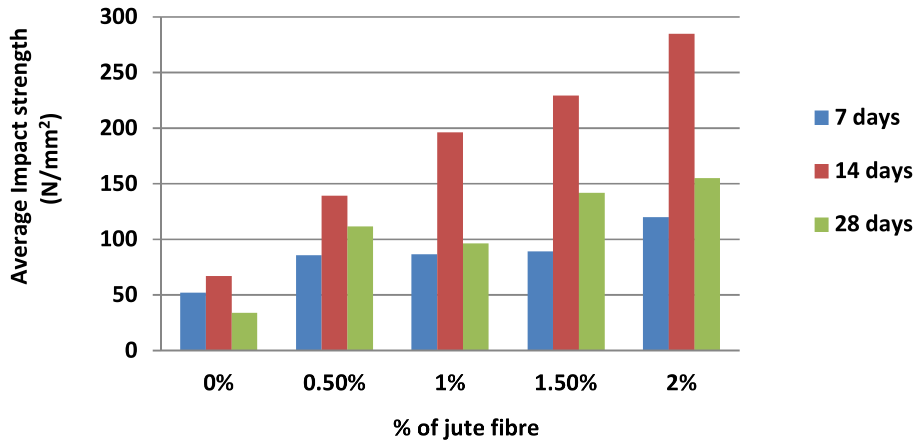

Fig. 4. JFRC impact strength at failure

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The findings revealed that the addition of jute fibre in concrete improved the impact energy and strength of the concrete, with the performance under impact load comparable to plain concrete. The impact strength of jute fibre reinforced concrete increased with increase in fibre content compared to plain concrete. The energy required to cause the first visibility crack and failure increased as the volume fraction of jute fibre increases. The number of blow required by jute fibre was more than the number of blow required for initial and final collapsed in plain concrete. This signifies proportionate increase in jute fibre content to number of blows as well as impact energy required for the final failure of the concrete. The presence of jute fibre in the matrix minimized cracks at failure and helped in better bonding of the concrete. The inclusion of jute fibre to concrete abetted as crack arrestor, and substantially improved the concrete dynamic properties.

5.2 Recommendations

Further research should be considered on long term assessment of JFRC, its durability characteristics and the effect of super-plasticizer addition on the matrix mix proportion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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